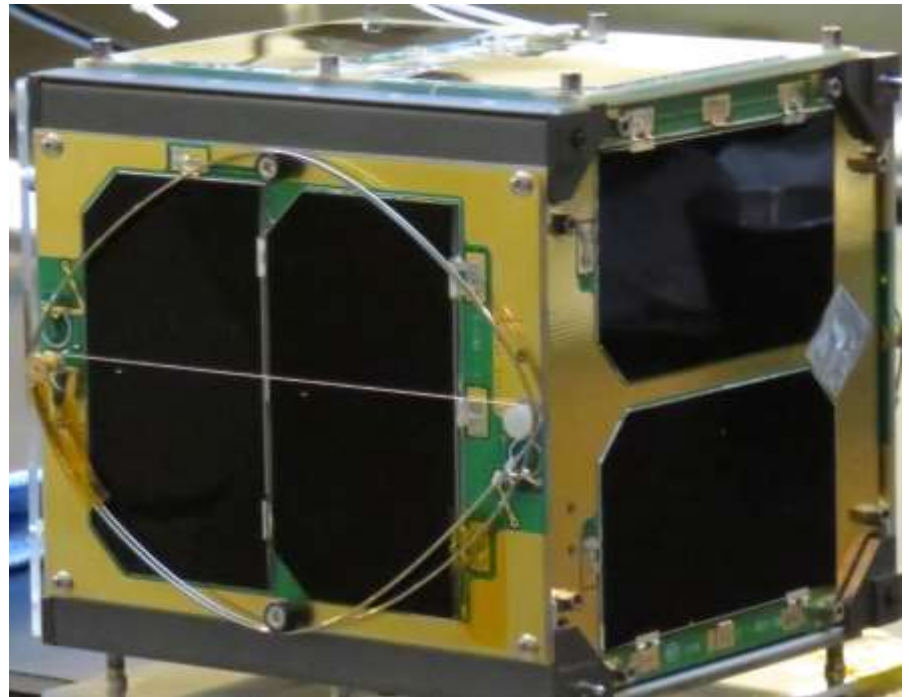


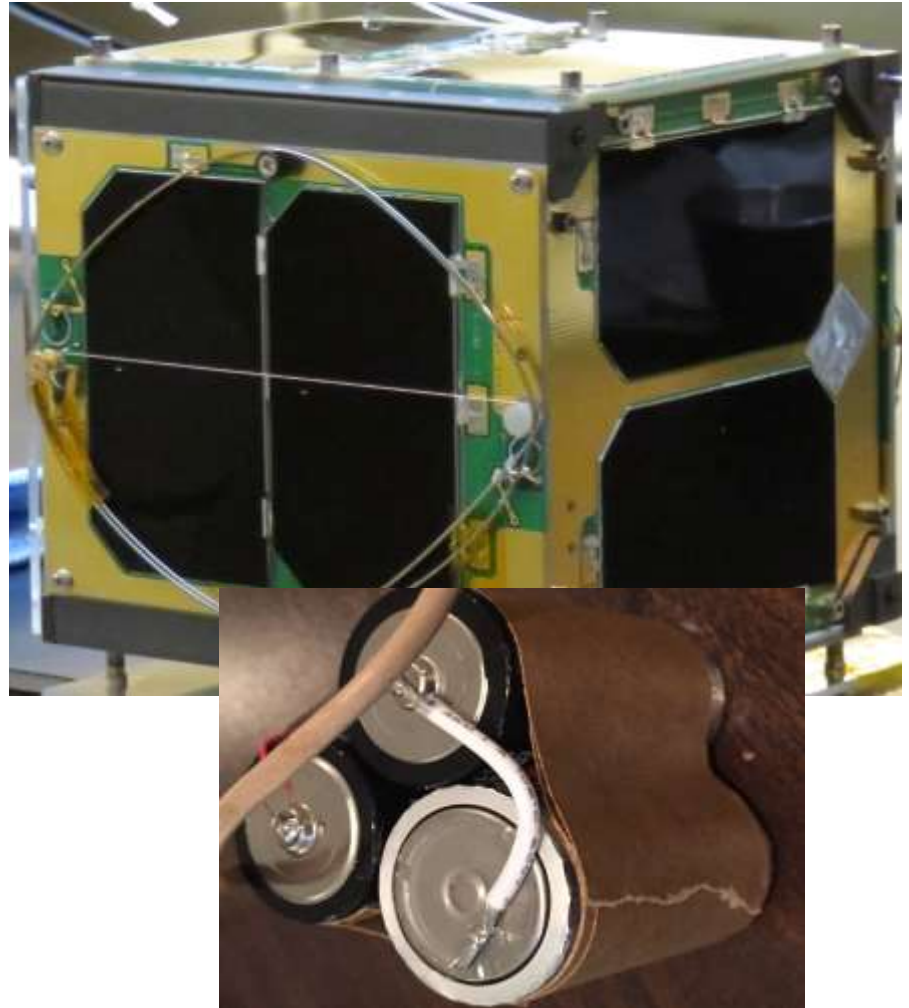
Experimenting with the Experiment

Burns Fisher, W2BFJ

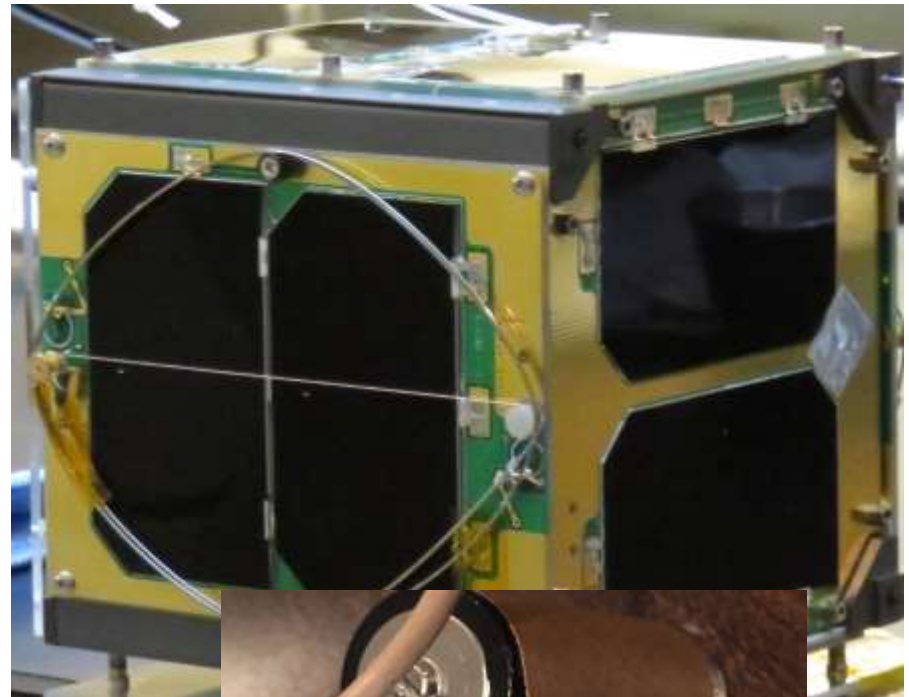
What Do These Objects Have in Common?



What Do These Objects Have in Common?



What Do These Objects Have in Common?



Here is a hint:



...and another



MEMS Gyros

- MicroElectroMechanical Systems rate gyros
- Originally Penn State Erie Undergrad experiment



LPY403AL

MEMS motion sensor:
dual-axis pitch and yaw ± 30 dps analog gyroscope

Features

- 2.7 V to 3.6 V single-supply operation
- Wide operating temperature range (-40 °C to +85 °C)
- High stability over temperature
- Analog absolute angular-rate outputs
- Two separate outputs for each axis (1x and 4x amplified)
- Integrated low-pass filters
- Low power consumption
- Embedded power-down
- Embedded self-test

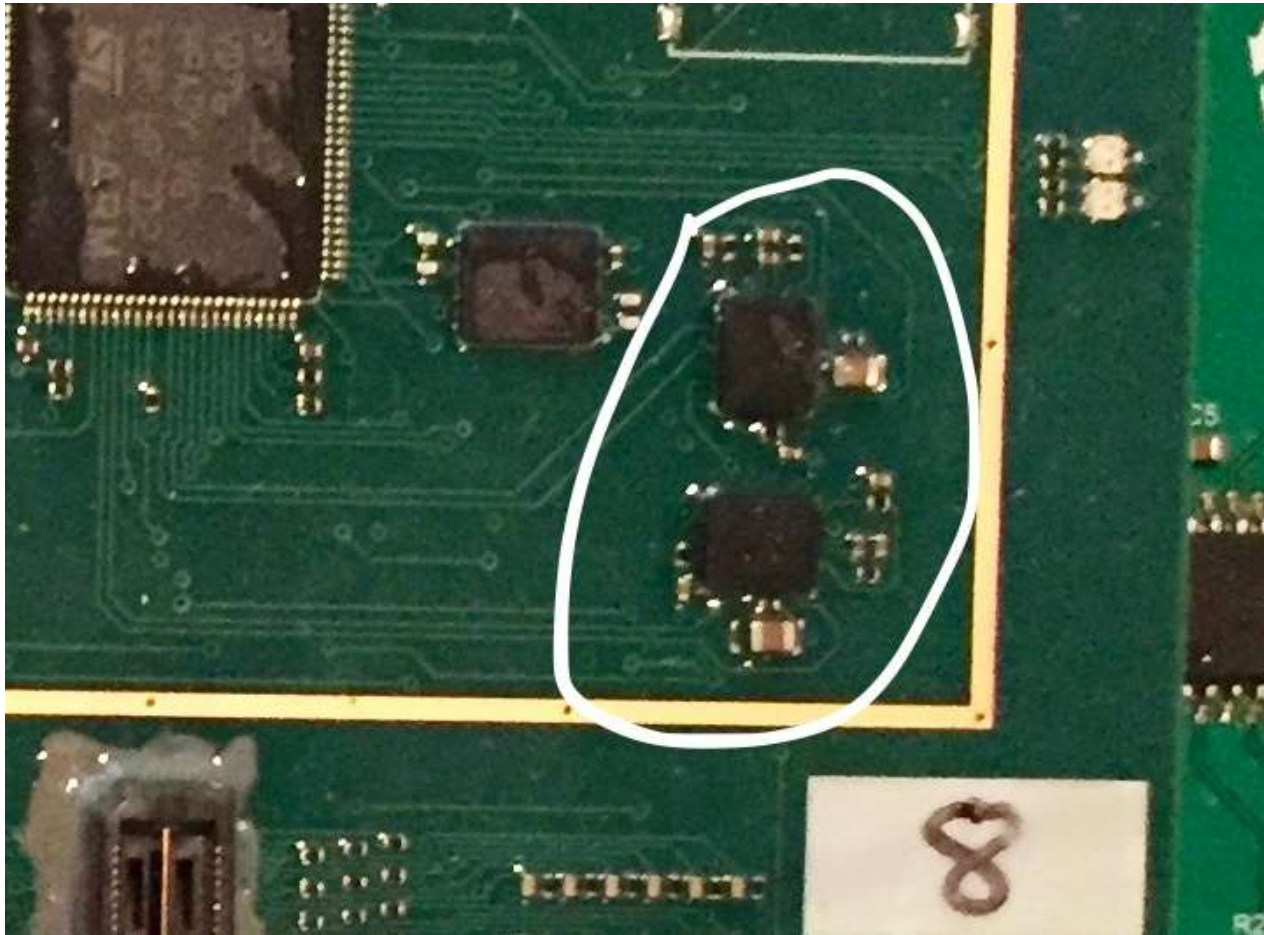


LGA-28 (4x5x1 mm)

The LPY403AL has a full scale of ± 30 dps and is capable of detecting rates with a -3 dB bandwidth up to 140 Hz.

The device includes a sensing element composed of a single driving mass, kept in continuous oscillation and capable of reacting, based on the Coriolis principle, when an angular rate is applied.

Mounting the Gyros

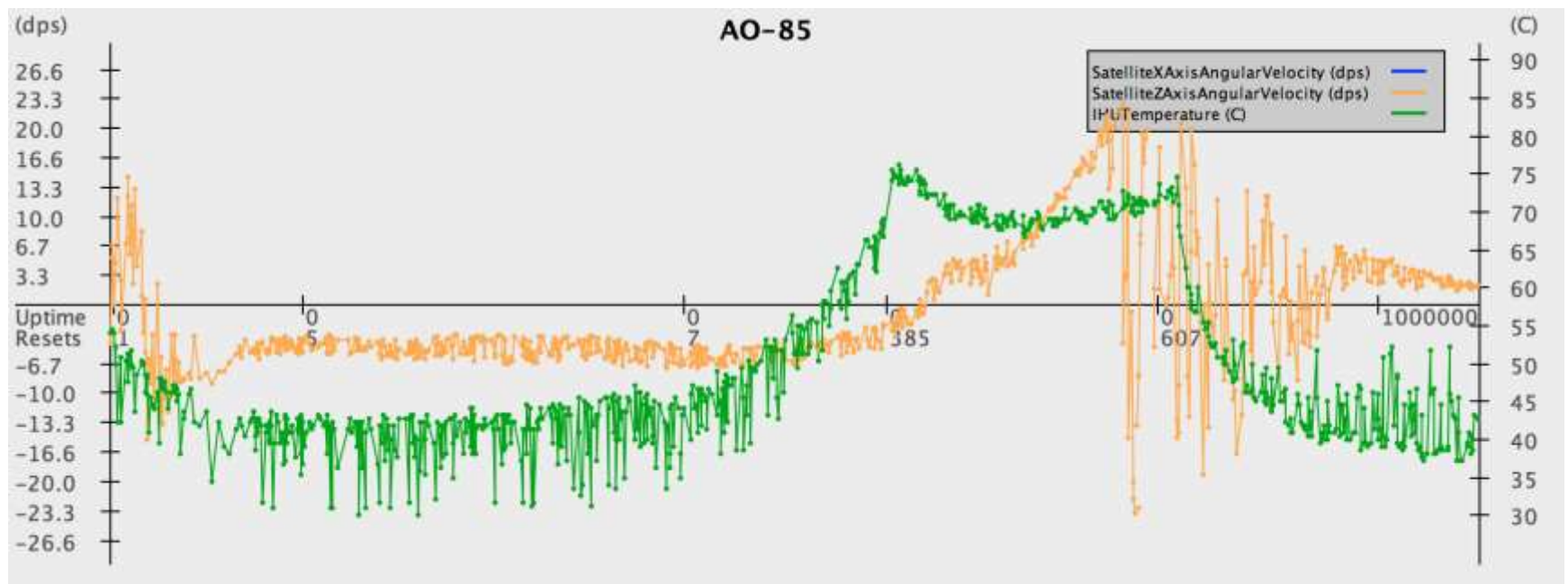


Received data

- Output from gyros is a voltage
 - 1.5V = rest
 - $\sim .5V = -30$ degrees per second (DPS)
 - $\sim 2.5V = +30$ DPS (5 RPM)
 - That is $\sim 33mV$ per DPS
- A/D Converter digitizes the voltages frequently
- Sent to the ground $\sim 4x$ per minute

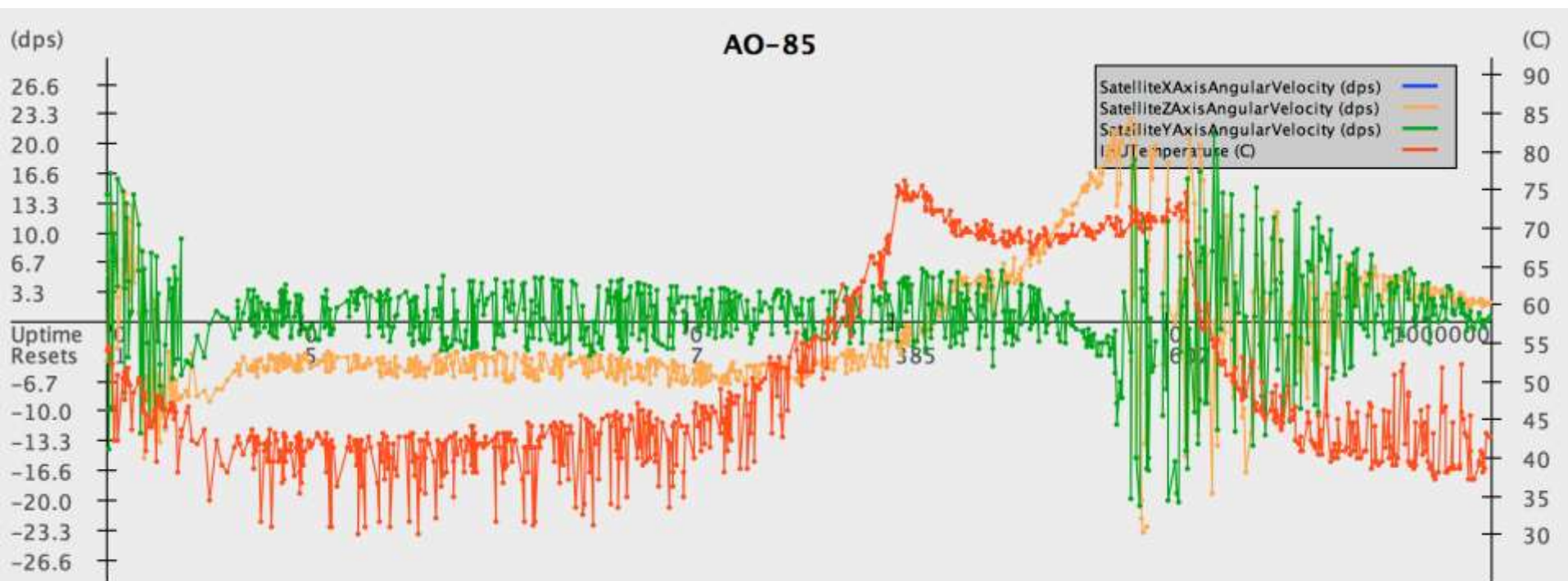
What does the data look like?

- Graph of Z-axis DPS vs Temperature
- From FoxTelem after loading worldwide data



A bit more

- Here is the same graph with the Y axis added (colors have changed too)



Brings Up Different Questions

- Why does spin increase with more sun?
- What do the different spins on different axes mean?
- What is going on right at the peak temperature?

- Why does spin increase with more sun?
 - Easy to answer:

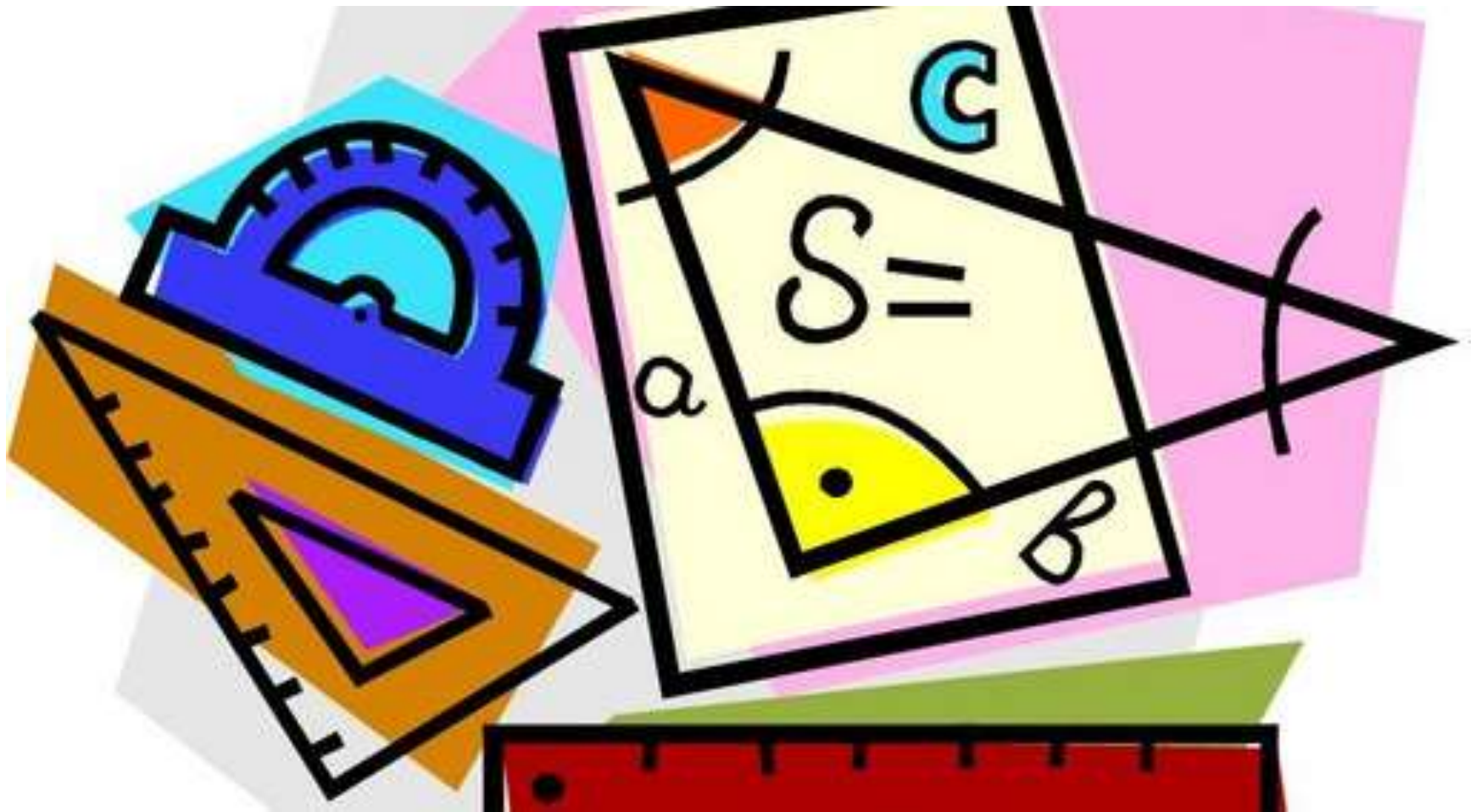


Brings Up Different Questions

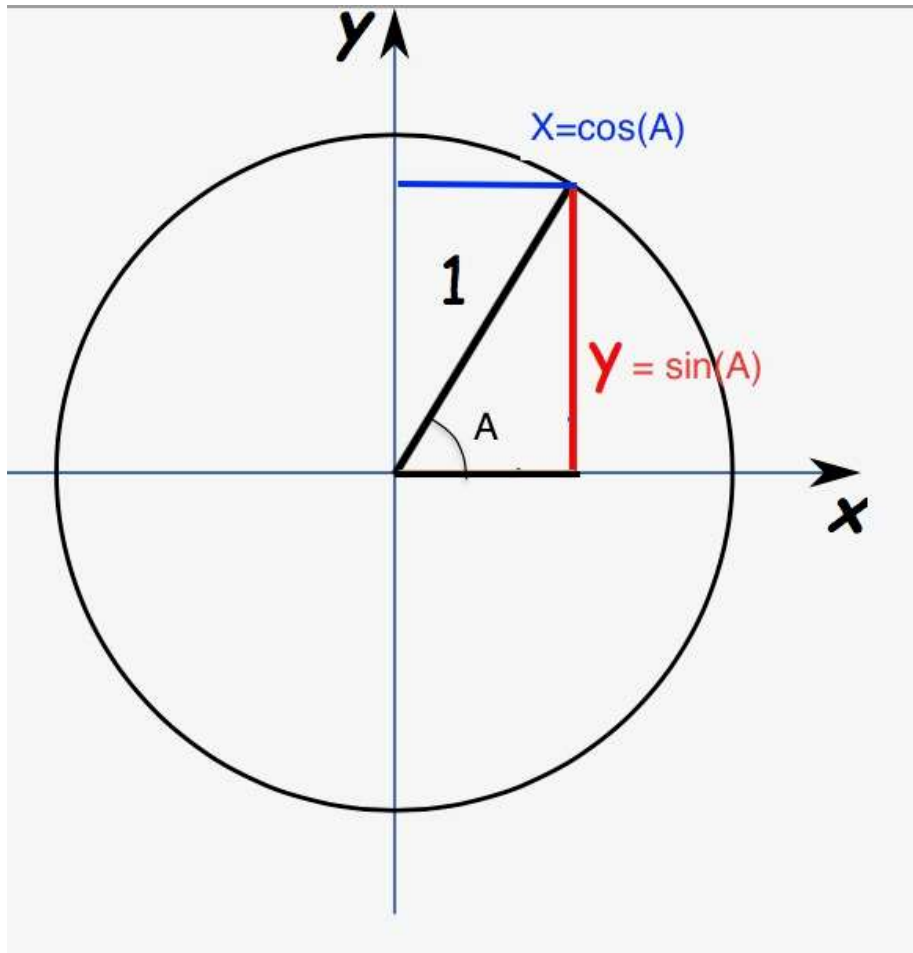
- Why does spin increase with more sun?
- What do the different spins on different axes mean?
- What is going on right at the peak temperature?

- What do the different spins on different axes mean?

Back to School?

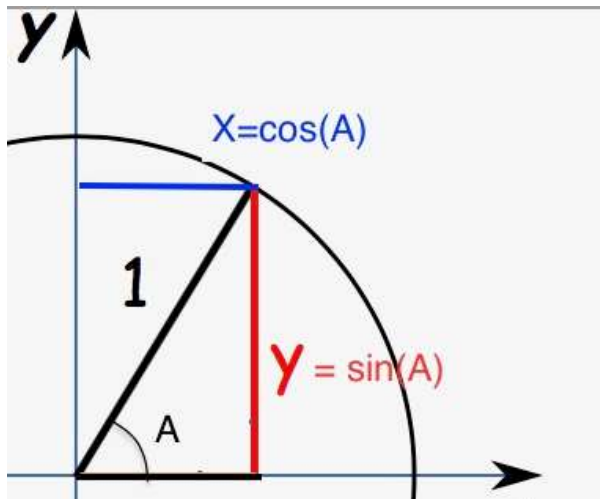


Quick Trig/Analytical Geometry Review



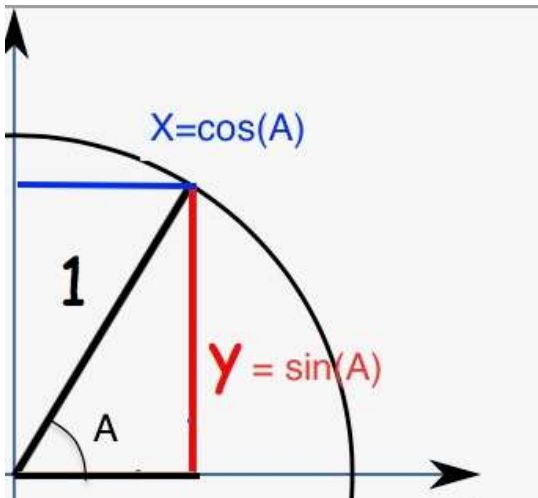
- Unit Circle
- Radius 1
- Angle A
- Cos X , Sin Y
- Tangent Y/X

Quick Trig/Analytical Geometry Review



- If you have x , y but not A and not radius r
- $r = \text{Sqrt}(x^2 + y^2)$
- $\text{SIN}(A) = y/r$ $\text{COS}(A) = x/r$
- $A = \text{ARCSIN}(y/r)$

MEMS and Geometry



- MEMS Gyro axes aligned along x and y of figure.
 - The gyro is spinning on the axis formed by the radius at speed r dps.
-
- Voila! The MEMS gyro x rate should read $r \cdot \cos(A)$ and the y rate will read $r \cdot \sin(A)$!
 - A calculation with ARCSIN gives you the angle A

All Very Nice But Prove It

- Remember the cake turner etc?
- The box contains the batteries.
- On top is IHU and transmitter
- Off to one side is FoxTelem



Angles

- Board tipped at an angle to spin axis



Results

Gyro Experiments

Raw Data					Scaler Rotation	Spin Axis Angle From Coordinate Basis Axes		
	Satellite Time	RPM			RPM	Degrees		
<i>Z Plane Flat</i>	Seconds	Z	Y	Z		X	Y	Z
No Rotation								
	14	0.00	0.00	0.00	0.00			
CW 3.75 RPM								
	136	-0.14	0.12	-4.32	4.32	88.17	88.38	2.44
	151	-0.12	0.30	-4.07	4.08	88.29	85.83	4.51
	165	0.08	0.24	-4.44	4.44	88.95	86.91	3.27
	180	-0.26	0.33	-4.46	4.48	86.67	85.83	5.34
	211	-0.22	0.01	-3.70	3.70	86.54	89.81	3.47
	226	-0.02	0.20	-4.79	4.79	89.81	87.66	2.34
	240	-0.02	0.39	-4.20	4.22	89.72	84.64	5.37
	255	0.20	0.01	-5.07	5.07	87.70	89.91	2.30
	284	0.24	0.60	-5.09	5.13	87.37	83.27	7.24
	299	0.02	0.18	-4.95	4.96	89.81	87.88	2.12

Results

Gyro Experiments

Raw Data					Scaler Rotatio n	Spin Axis Angle From Coordinate Basis Axes		
	Satellite Time	RPM			RPM	Degrees		
	Seconds	Z	Y	Z		X	Y	Z
<i>Z Plane Flat</i>								

CCW 3.75RPM

331	0.37	-0.18	4.33	4.35	85.07	87.59	5.49
345	0.13	-0.22	3.71	3.72	87.99	86.55	3.99
360	0.24	-0.09	4.08	4.09	86.69	88.69	3.56
374	0.03	0.02	4.15	4.15	89.55	89.72	0.53
402	-0.30	0.00	3.37	3.38	84.89	90.00	5.11
416	0.48	-0.48	4.20	4.25	83.46	83.52	9.22
431	-0.27	-0.32	3.94	3.96	86.06	85.41	6.06

Bench Results

<i>Degree On X Axis</i>	Time	X	Y	Z	Scalar	AngleX	AngleY
CW 3.75 RPM							
	694	0.91	0.17	-4.31	4.41	78.13	87.7
	708	0.85	0.13	-4.10	4.19	78.35	88.1
	723	0.88	0.02	-4.75	4.83	79.52	89.7
	737	0.92	0.03	-4.37	4.47	78.09	89.6
	752	1.16	0.30	-3.84	4.03	73.21	85.7
	766	0.62	-0.04	-3.59	3.65	80.24	89.4
	781	1.03	0.25	-3.89	4.03	75.21	86.4
CCW 3.75 RPM							
	829	-0.87	0.06	3.85	3.95	77.34	89.1
	844	-0.85	-0.01	4.14	4.23	78.34	89.8
	859	-0.73	0.06	3.99	4.06	79.67	89.1

Experiment Summary

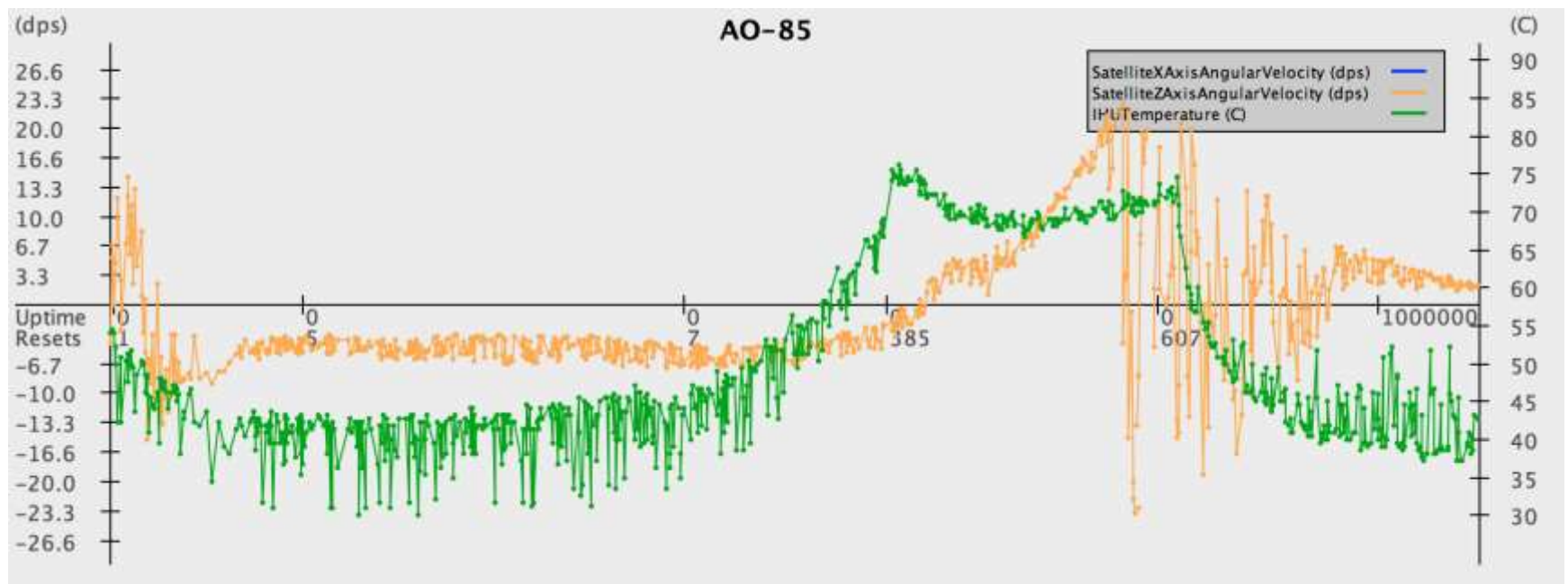
- Significant errors introduced
 - My home experiment setup
 - Cake turner likely not perfect
 - A/D converter on spacecraft not perfectly linear
- However, the general idea is proven

What is Next?

- Use it with the real satellites!
- Lots of questions still to answer.

Remember this?

- Graph of Z-axis DPS vs Temperature
- From FoxTelem after loading worldwide data



We Never Answered This Q

- Why does spin increase with more sun?
- What do the different spins on different axes mean?
- What is going on right at the peak temperature?

We Never Answered This Q

- Why does spin increase with more sun?
- What do the different spins on different axes mean?
- What is going on right at the peak temperature?
 - *Left As An Exercise For The Reader*

Suggestions

- Repeat my experiment
 - Get some cheap MEMs evaluation boards with an I2C or SPI interface and a Raspberry Pi to record
- Use my spreadsheet (URL next page) and play with data from FoxTelem.
 - Download all data from the server.

Other Questions

- Were gyros ok immediately after launch?
- Can we see satellite “flip” around the equator?
- Can we see nutation (spin axis rotation)
- Suggest new experiments!

Spread Sheet Is Available

- <http://burnsfisher.net/AMSAT/Symposium2017/MEMSGyroData.xlsx>
- I have it here
- Send me mail: w2bfj@amsat.org